X-RADIATION IMAGERY DEVICE AND PROCESS FOR MAKING THIS DEVICE

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TECHNICAL DOMAIN

This invention relates to an X-radiation imagery device, for example with large dimensions, which can be operated in radiography mode or in radioscopy mode, and the process for making such a device.

The invention is particularly applicable to medical imagery.

STATE OF PRIOR ART

A distinction is made between two application types of radiological imagery techniques, that are different from each other by their acquisition principle. Only one image is acquired in a radiography application, whereas in a radioscopy application a series of images is acquired at a rate of twenty-five video images per second.

The image for radiography systems on the market at the moment is taken analogically, whereas it is digital in radioscopy systems.

The advantage of obtaining a digital image is such that several solutions are proposed to transform the detected analogue signal for radiography applications, into a digital signal (image processing means, data archiving, etc.).

In radiography devices, means of detecting X-radiation comprise films sensitive to X-rays and that

emit light that is read by reinforcing screens (for example made of BaFBr or BaFCl).

One first embodiment used to obtain digital information consists of coupling these films to a video camera itself coupled to an image intensifier. The digital image thus obtained is instantaneous but its quality is mediocre (poor spatial resolution, poor conversion efficiency, noise, etc.).

A second embodiment consists of replacing the film with its reinforcing screens by a luminous screen with a photostimulable memory. This screen keeps the stored energy in memory during exposure to X-radiation. The information contained in this energy is read later after the screen has been scanned by a laser beam. This embodiment has the disadvantages that the radiological device is large, the digital image is not obtained instantaneously and the information processing time is long (from 40 to 60 seconds).

A third embodiment consists of using a detector comprising a photoconductor based on selenium making use of the xeradiography principle; the charge initially created at the surface of the selenium by Corona effect depends on the number of X-photons detected. The charge variations are read by microprobes due to a capacitive effect. After exposure to X-rays and after the created charge has been read, the selenium layer needs to be recharged. The radiological device using this embodiment is large and information is read slowly, in about fifteen seconds, so that it cannot be used in radioscopy mode.

In devices used in radioscopy, the digital detection means comprise a Radiological Image Intensifier (IIR) also called a brightness amplifier. This detector is used for creating imagery with excellent sensitivity in real time, but the image field is limited by the maximum size of the vacuum tubes (40 cm), a modest spatial resolution, image distortions and large dimensions.

New digital two-dimensional detectors with direct read-out have been introduced over the last few years, however their use is limited to radiography mode only. These new detectors have the special features that they can be made with large dimensions (for example 40x40 cm^2).

Detectors have also appeared with luminous screens associated with an optical charge coupled device (CCD) camera, requiring an optical reduction for large fields, and there are also detectors with flat panels based on amorphous silicon like those described in document reference [1] at the end of this description. This document describes the combination of a network of thin a-Si:H film transistors and an a-Fe X-ray photoconductor on a glass substrate.

The technology used to make flat panels based on amorphous silicon is based on the technology used to make liquid crystal displays. A panel is a charge reading matrix made of amorphous silicon (a-Si:H) comprising pixels. The panel is read with a system of switches (transistors) with control by rows and reading by columns. The entire column is read during scanning and the electronic processing of the charge is made on remote electronics. This reading process generates high noise (2 000 to 5 000 electrons).

There are two embodiments of a detector using this type of reading panel.

The most frequent embodiment consists of recovering each pixel in the reading panel of a photodiode and putting the photodiodes into contact with a scintillator, for example made of CsI : Tl. The photodiodes convert light radiation into electric charges read by the panel based on amorphous silicon. This type of device has an efficiency problem related to indirect detection of photons; the amplitude of the detected signal is low. Furthermore, the use of CsI makes it impossible to obtain good absorption of photons by CsI and measurements with good spatial resolution. A compromise has to be made. Furthermore, a luminescence phenomenon that occurs after the X-radiation has stopped in the scintillator makes this device unusable in radioscopy mode. Finally, the filling rate of this type of device is low (from 50 to 70%).

A second embodiment consists of depositing a coat of amorphous selenium on the reading panel, this coat of amorphous selenium directly converting the X-radiation into electric charges. The selenium imposes some constraints related to the fact that it is a lightweight element. This characteristic makes it necessary to deposit a thick layer of it to be able to stop photons, to the detriment of the efficiency of the charge carrier collection. And this requires the application of a large potential difference (of the order of magnitude of 10 V/μm) to polarize the

detector, which is penalizing for use in medical applications.

In conclusion, there is no device available at the moment capable of operating in radiography mode and in radioscopy mode.

The purpose of the invention is to produce a digital imagery device comprising a two-dimensional digital detector capable of operating equally well in radiography mode and in radioscopy mode, with good detection efficiency and that can be made in large dimensions.

Patent application reference [4] defined at the end of the description describes an X-ray image sensor comprising a substrate on which a pixel network and a reading circuit are placed side by side, followed by an absorbent layer and a transparent conducting layer on top.

<u>DISCLOSURE OF THE INVENTION</u>

This invention relates to an X-radiation imagery device comprising at least one detection matrix made of a semiconducting material comprising pixels to convert incident X-photons into electric charges and a silicon-based electric charges reading panel comprising several electronic devices, each electronic device being integrated by pixel, characterized in that each detecting matrix is made of a layer of semiconducting material deposited in vapour phase on the electric charges reading panel.

Therefore the invention relates to a fully integrated semiconductor based device used in radiological imagery to make large area digital images (for example from 20x20 cm^2 to 40x40 cm^2). This device has the advantage that it is a structure with low noise, with advanced electronics so that they can operate in mixed radiography/radioscopy mode with high

manufacturing efficiencies and moderate manufacturing cost.

The invention also relates to a process for making an X-radiation imagery device comprising at least one detecting matrix made of a semiconducting material comprising pixels to convert incident X-photons into electric charges, and an electric charges reading panel based on silicon comprising several electronic devices, each electronic device being integrated by pixel, characterized in that each detecting matrix is obtained a vapor phase deposition of a semiconductor on the electric charges reading panel.

Advantageously, the evaporation properties of this semiconductor are such that the deposition can be done at low temperature.

Advantageously, the semiconducting material used to make the matrix of detection pixels is CdTe, HgI_2 or PbI_2.

Advantageously, electronic devices made using a 1.25 μm technological system are used.

Advantageously, electronic devices made using a 0.1 μm technological system are used.

The process according to the invention is compatible with the monocrystalline silicon technology now used in microelectronics, which has the following advantages:

- it benefits from developments in standard microelectronic systems in which the diameter of silicon ingots is increasing over the years (from 10 cm in 1980 to 35 cm in 2000), to limit the cost of the fully integrated detector.

• Eliminate coupling or connection steps between two elements since a semiconductor based detection layer is deposited directly on the monocrystalline silicon based reading circuit comprising advanced electronics (preamplifier, amplifier, filters, etc.).

• The crystalline quality of the detection material for use.

BRIEF DESCRIPTION OF THE FIGURES

Figure 1 illustrates the X-radiation imagery device according to the invention and the process for making it.

Figures 2A to 2E illustrate the process for making a radiological imagery device according to the invention.

DETAILED PRESENTATION OF EMBODIMENTS

This invention relates to an X-radiation imagery device that comprises at least one matrix made of a semiconducting material to convert incident X-photons into electric charges and comprising pixels 11, each matrix being arranged on a monocrystalline silicon based electric charges reading panel 10 comprising several electronic devices, each electronic device being integrated by pixel 11 in the said matrix.

The charges reading panel, for example made using conventional 0.1 μm to 1.25 μm microelectronic systems (diameter a few tens of centimeters) is used as a substrate on which the matrix made of semiconducting based detection material is deposited, and converts incident X-photons into electric charges.

For example, the matrix made of a semiconducting material may be deposited using the CSVT method starting from a source 12 containing the semiconducting material 13, inside a chamber 14 containing a controlled atmosphere of an inert gas.

As described in document reference [2], the main characteristics of the use of the CSVT (Close-Spaced Vapor Transport) method to generate thin layers are that it is easy to implement, inexpensive and can be used for the growth of large areas.

In the invention, the source 12 comprising the semiconducting material that may be solid or in powder form, is heated to a temperature T1 of the order of 600°C. For example, the semiconducting material used may be CdTe, PbI_2 or HgI_2. This source 12 is separated from substrate 10 by a short distance that varies from 1 to 10 mm. The substrate temperature is regulated to a temperature T2 less than the temperature of the source. It varies from 200°C to 600°C depending on the nature of the semiconductor used and the required quality of the layer. The temperature gradient created enables transport of material between the source 12 and the substrate 10. The physical properties of semiconductors such as CdTe, PbI_2 or HgI_2 associated with use of a CSVT method help to reduce strain on the substrate by not exceeding a temperature (200 to 450°C) compatible with the resistance to heat of the silicon in electronic devices.

Different conditions must be satisfied in order to deposit this type of semiconducting layer at low temperature. The following steps are necessary:

- heat the source up to its sublimation temperature,
- make the deposit onto a material such that the deposited material can be reorganized in the form of a layer (the material may be heated in advance),
- optimise the distance between the source and the substrate to diffuse vapor between the source and the supported and undispersed substrate,
- obtain a sufficiently high deposition rate, in other words greater than a few μm/h, so that a layer a few hundred microns thick capable of efficiently stopping photons can be made in a deposition time compatible with industrialization of the detector,
- keep the substrate, that comprises the reading circuit, at a temperature such that the circuit is not damaged (in other words at a temperature of less than 450°C for monocrystalline silicon, and less than 250°C for amorphous silicon).

When choosing a useable semiconducting material, all its physical properties have to be taken into account and a compromise is necessary. The following data are available for a given material:

- the absorption of a material increases as its atomic number z increases,
- a material with a given thickness absorbs X-rays better if its density is higher (the target absorption is between 70% and 90%),

- the detector noise reduces as its resistivity increases,

- the amount of electrical information generated by the interaction between the material and X-rays increases as the energy of electron-hole pairs reduces,

- the life must be greater than the extraction time, which is the time necessary for the electrons and holes to be extracted,

- the rate of increase of the flux increases when the mobility, which is function of the atomic number and the density, is increased,

- the detection for a given applied electric field improves when the quality criterion $\mu\tau$, which is the product of the mobility by the life, increases,

- for equivalent physical characteristics, the material requiring application of the lowest possible electric field shall be chosen.

Table 1 contained at the end of the description is a comparative table showing different possible detection materials, E (V/cm) being the electrical field conventionally applied to the material considered.

Therefore, the invention combines the use of a semiconductor based detection materials for which the deposition method is capable of making large areas (a few dm^2) with a reading circuit developed on a solid wafer of monocrystalline silicon (diameter 10 to 30 cm) integrating advanced electronics dedicated to the detection of X-radiation (amplification, filters and processing) that can be integrated in a pixel, for example with a size of 100 to 200 μm.

The result is a large area X-radiation imagery device that is completely integrated and that has considerably improved signal/noise performances.

In this imagery device, an electronic device is placed as close as possible to each detector pixel. Consequently, connecting capacitances are minimized and the consequence is a large reduction in the read noise compared with devices according to prior art.

Furthermore, the use of electronic devices made from monocrystalline silicon means that a detected signal amplifier with an excellent quality can be made.

Finally, the combination of a detector with a low connecting capacitance and an electronic device with a good quality amplifier, means that the imagery device according to the invention has negligible reading noise, lower than the noise of the photon, thus making it possible to take images at low doses comparable with images obtained in radioscopy mode.

Thus, the imagery device according to the invention can operate equally well in radiography mode and in radioscopy mode.

Each electronic device dedicated to detection and processing of the charge deposited in the semiconducting material is a device that can contain several X-ray detection functions. For example, the device according to the invention comprises advanced electronics like that described in document reference [3] that can be integrated for example in a 150 μm x 150 μm pixel. Each electronic device may comprise a reading circuit and an integration circuit (that stores a number of electrons that will be transformed into an

analogue voltage and will then be digitized) and/or a counting circuit. Means can be added on the input side of this basic block to avoid saturating the reading means, for example with a continuous darkness current circulating in the detector.

The invention also relates to the process for making such an imagery device. Therefore this process, as described above, consists of transferring a semiconductor by vapour phase with evaporation properties such that deposition at low temperature is possible on a substrate compatible with its temperature resistance, and in this invention this substrate is the monocrystalline silicon based reading circuit integrating the advanced electronics.

We will now consider two successive embodiments of the imagery device according to the invention.

In a first embodiment, a 30 cm silicon substrate is used with electronics made using the 0.1 μm technological system.

Figure 2A illustrates a monocrystalline silicon slice 20 (diameter 30 cm), the monocrystalline silicon part with integrated electronics having reference 21. This figure also shows:

- control and command pins 22;
- the 100 to 200 μm pixels 23 comprising dedicated electronics.

Figure 2B illustrates the 20 cm x 20 cm cutout 25 of a monocrystalline silicon wafer with integrated electronics used as a substrate during deposition of a semiconducting layer using the CSVT method.

Figures 2C and 2D illustrate the semiconducting layer 24 deposited using the CSVT method, for example to form a 20 cm x 20 cm element 25.

Figure 2E illustrates the butt connection of four elements, for example 20 cm x 20 cm elements 25 to obtain a large area digital detector for use in radiology, giving an area (40 cm x 40 cm) in accordance with the chosen example.

This embodiment has the following advantages:

- it gives a wide field by assembling several detectors;
- the use of very advanced electronic functions;
- the production of electronic devices using standard microelectronic technologies.

In a second embodiment, a 15 cm silicon substrate is used with electronics made using the 1.25 μm technological system. Electronics made using this type of technology is quite sufficient to integrate the electronics dedicated to radiology in a 100 μm pixel. Its advantage is its immediate availability and low manufacturing costs. For radioscopy applications, four 10 cm x 10 cm detectors can be combined to give a 20 cm x 20 cm detection area which is sufficient for a medical application.

Table 1

	z	Density	Resistivity (ohm.cm)	μ 60 keV (cm-1)	Epair e-t(eV)	μ.tau electron (cm 2/V)	E(V/cm)
Si	14	2.3	1, E+03	0.2	3.6	1,E-02	1,E+03
GaAsLPE	31 – 33	5.3	1, E+07	6	4.7	?	?
a-Se	34	4.8	1, E+12	10.0	30-50	1,E-07	3,E+05
HgI2 ceram	80 – 53	6.4	5, E+10	31.0	4.2	1,E-07	1,E+04
PbO	82 – 8	?	1, E+13	?	15	?	3, E+04
PbI2 Evap.	82 – 53	5.5	1, E+12 to 1, E+13	32.1	5	2,E-06	2,E+04
CdTe CSVT	48 – 52	5.9	1, E+9 to 1, E+10	40.0	4.5	8,E-04	1,E+03
TIBr Evap.	81 – 35	7.5	1, E+10	31.6	6.5	4,E-07	2,E+04

REFERENCES

[1] «Amorphous Semiconductors Usher In Digital X-Ray Imaging» by John Rowlands and Safa Kasap (Physics Today, November 1997, pages 24 to 30)

[2] «Growth Of Semiconductors By The Close-Spaced Vapor Transport Technique: A Review» by G. Perrier, R. Philippe and J.P Dodelet (J. Mater. Res. 3 (5), September/October 1988, pages 1031 to 1042)

[3] «Readout For a 64x64 Pixel Matrix With 15-Bit Single Photon Counting» by M. Campbell, E.H.M. Heijne, G. Meddeler, E. Pernigotti and W. Snoeys (Nuclear Science Symposium, Albuquerque, November 12 1997)

[4] WO 96/33424.